Java Exceptions

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Motivation

- Report errors, by delegating error handling to higher levels
- Callee might not know how to recover from an error
- Caller of a method can handle error in a more appropriate way than the callee

- Localize error handling code, by separating it from functional code
- Functional code is more readable
- Error code is centralized, rather than being scattered

The world without exceptions (I)

- If a non locally remediable error happens while method is executing, call `System.exit()`

- A method causing an unconditional program interruption in not very dependable (nor usable)

The world without exceptions (II)

- If errors happen while method is executing, we return a special value
- Special values are different from normal return value (e.g., null, -1, etc.)

- Developer must remember value/meaning of special values for each call to check for errors
- What if all values are normal?
  - ♦ double pow(base, exponent)
  - ♦ pow(-1, 0.5); //not a real

Real problems

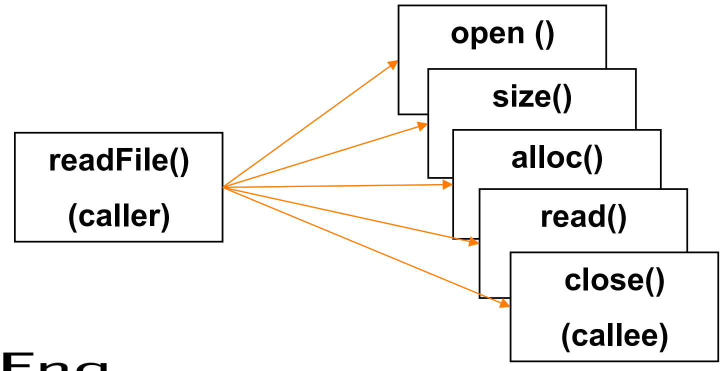
- Code is messier to write and harder to read

```
if( somefunc() == ERROR ) // detect error
   //handle the error
else
   //proceed normally
```

- Only the direct caller can intercept errors (no delegation to any upward method)

Example – Read file

- open the file
- determine file size
- allocate that much memory
- read the file into memory
- close the file



readFile()
(caller)

open ()

size()

alloc()

read()

close()
(callee)

All of them can fail

Correct (but boring)

```
int readFile {
   open the file;
   if (operationFailed)
      return -1;
   determine file size;
   if (operationFailed)
      return -2;
   allocate that much memory;
   if (operationFailed) {
      close the file;
      return -3;
   }
   read the file into memory;
   if (operationFailed) {
      close the file;
      return -4;
   }
   close the file;
   if (operationFailed)
      return -5;
   return 0;
}
```

Lots of error-detection and error-handling code

To detect errors we must check specs of library calls (no homogeneity)

Unreadable

Wrong (but quick and readable)

```
int readFile {

   open the file;
   determine file size;
   allocate that much memory;
   read the file into memory;
   close the file;

   return 0;
}
```

Which one would YOU use ?

☺

Using exceptions (nice)

```
try {
        open the file;
        determine file size;
        allocate that much memory;
        read the file into memory;
        close the file;
} catch (fileOpenFailed) {
        doSomething;
} catch (sizeDeterminationFailed) {
        doSomething;
} catch (memoryAllocationFailed) {
        doSomething;
} catch (readFailed) {
        doSomething;
} catch (fileCloseFailed) {
        doSomething;
}
```

Basic concepts

- The code causing the error will generate an exception
  - Developers code
  - Third-party library
- At some point up in the hierarchy of method invocations, a caller will intercept and stop the exception
- In between, methods can
  - Ignore the exception (complete delegation)
  - Intercept without stopping (partial delegation)

Syntax

- Java provides three keywords
  - Throw
    - Generates an exception
  - Try
    - Contains code that may generate exceptions
  - Catch
    - Defines the error handler
- We also need a new entity
  - Exception class

Generation

1. Declare an exception class
2. Mark the method generating the exception
3. Create an exception object
4. Throw upward the exception

Generation

```
// java.lang.Exception                               (1)
public class EmptyStack extends Exception {
}

class Stack{                                        (2)
   public Object pop() throws EmptyStack {

      if(size == 0) {                                (3)
         Exception e = new EmptyStack();
         throw e;
      }                  (4)
      ...
   }
}
```

throws

- Method interface must declare exception type(s) generated within its implementation (list with commas)

- Either generated and thrown by method, directly
- Or generated by other methods called within the method and not caught

throw

- Execution of current method is interrupted immediatelly
- Catching phase starts

Interception

- Catching exceptions generated in a code portion

```
try {
   // in this piece of code some
   // exceptions may be generated
   stack.pop();
   ...
}
catch (StackEmpty e) {

   // error handling
   System.out.println(e);
   ...
}
```

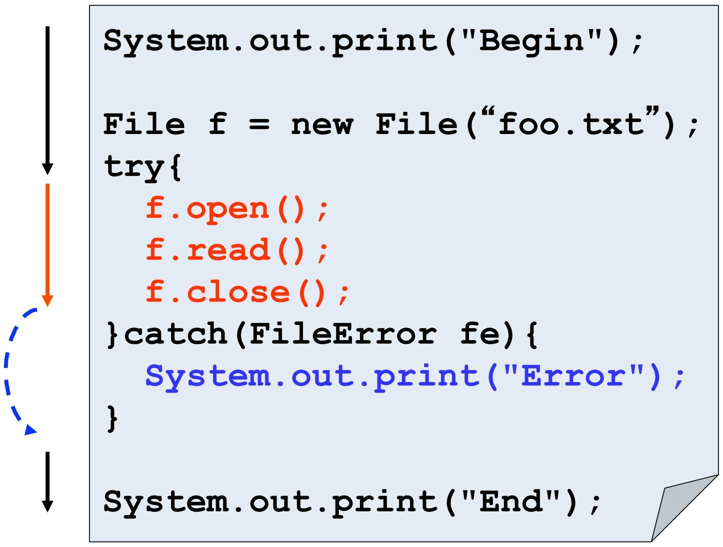
Execution flow

- open and close can generate a FileError
- Suppose read does not generate exceptions

```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
   f.open();
   f.read();
   f.close();
}catch(FileError fe){
   System.out.print("Error");
}

System.out.print("End");
```

Execution flow

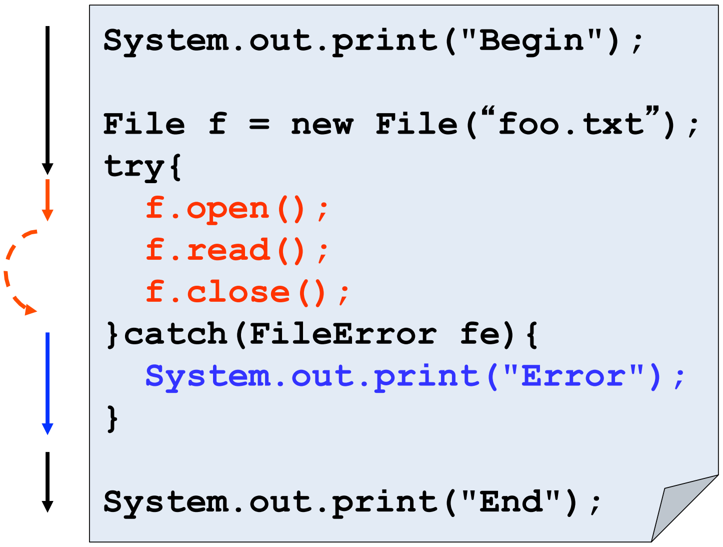
- No exception generated



```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
   f.open();
   f.read();
   f.close();
}catch(FileError fe){
   System.out.print("Error");
}

System.out.print("End");
```

Execution flow

- open() generates an exception
- read() and close() are skipped



```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
   f.open();
   f.read();
   f.close();
}catch(FileError fe){
   System.out.print("Error");
}

System.out.print("End");
```

Multiple catch

- Capturing different types of exception is possible with different catch blocks

```
try {
  ...
}
catch(StackEmpty se) {
   // here stack errors are handled
}
catch(IOException ioe) {
   // here all other IO problems are handled
}
```

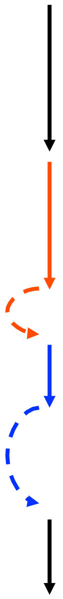
Execution flow

- open and close can generate a FileError
- read can generate a IOError

```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
  f.open();
  f.read();
  f.close();
}catch(FileError fe){
  System.out.print(“File err”);
}catch(IOError ioe){
  System.out.print(“I/O err”);
}

System.out.print("End");
```

Execution flow

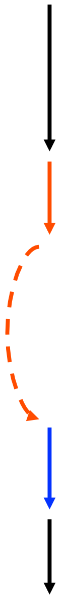
- `close` fails
- “File error” is printed
- Eventually program terminates with “End”



```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
  f.open();
  f.read();
  f.close();
}catch(FileError fe){
  System.out.print(“File err”);
}catch(IOError ioe){
  System.out.print(“I/O err”);
}

System.out.print("End");
```

Execution flow

- `read` fails
- “I/O error” is printed
- Eventually program terminates with “End”



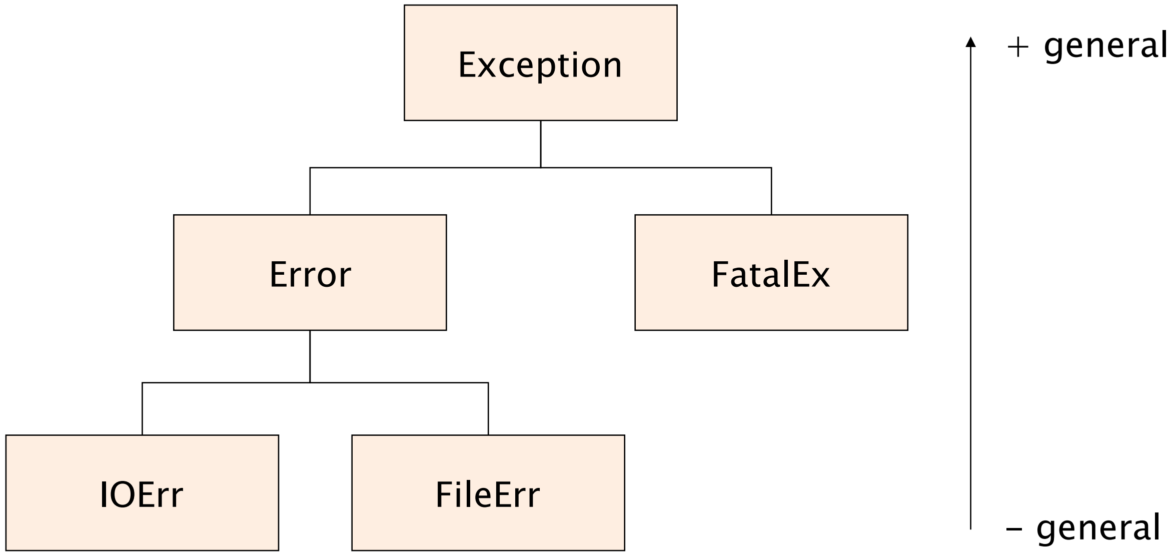
```
System.out.print("Begin");

File f = new File(“foo.txt”);
try{
  f.open();
  f.read();
  f.close();
}catch(FileError fe){
  System.out.print(“File err”);
}catch(IOError ioe){
  System.out.print(“I/O err”);
}

System.out.print("End");
```

Matching rules

- Only one handler is executed
- The more specific handler is selected, according to the exception type

- Handlers must be ordered according to their “generality”

Matching rules



Matching rules

```
class Error   extends Exception{}
class IOErr   extends Error{}
class FileErr extends Error{}
class FatalEx extends Exception{}

try{ /*…*/ }
catch(IOErr ioe){ /*…*/ }
catch(Error er){ /*…*/ }
catch(Exception ex){ /*…*/ }
```

– general

+ general

Matching rules

```
class Error   extends Exception{}
class IOErr   extends Error{}
class FileErr extends Error{}
class FatalEx extends Exception{}

try{ /*…*/ }
catch(IOErr ioe){ /*…*/ }
catch(Error er){ /*…*/ }
catch(Exception ex){ /*…*/ }
```

IOErr is generated

Matching rules

```
class Error   extends Exception{}
class IOErr   extends Error{}
class FileErr extends Error{}
class FatalEx extends Exception{}

try{ /*…*/ }
catch(IOErr ioe){ /*…*/ }
catch(Error er){ /*…*/ }
catch(Exception ex){ /*…*/ }
```

Error or FileErr is generated

Matching rules

```
class Error   extends Exception{}
class IOErr   extends Error{}
class FileErr extends Error{}
class FatalEx extends Exception{}

try{ /*…*/ }
catch(IOErr ioe){ /*…*/ }
catch(Error er){ /*…*/ }
catch(Exception ex){ /*…*/ }
```

FatalEx is generated

Nesting

- Try/catch blocks can be nested
- E.g. error handler may generate new exceptions

-
  ```
  try{ /* Do something */ }
  catch(…){
     try      { /* Log on file */ }
     catch(…){ /* Ignore */       }
  }
  ```

Generate and catch

- When calling code, which possibly raises an exception, the caller can
  - Catch
  - Propagate
  - Catch and re-throw

[1] Catch

```
class Dummy {
  public void foo(){
    try{
      FileReader f;
      f = new FileReader(“file.txt”);
    } catch (FileNotFound fnf) {
       // do something
    }
  }
}
```

[2] Propagate

```
class Dummy {

  public void foo() throws FileNotFound{
    FileReader f;
    f = new FileReader(“file.txt”);
  }

}
```

[2] Propagate (cont'd)

- Exception not caught can be propagated till main() and VM

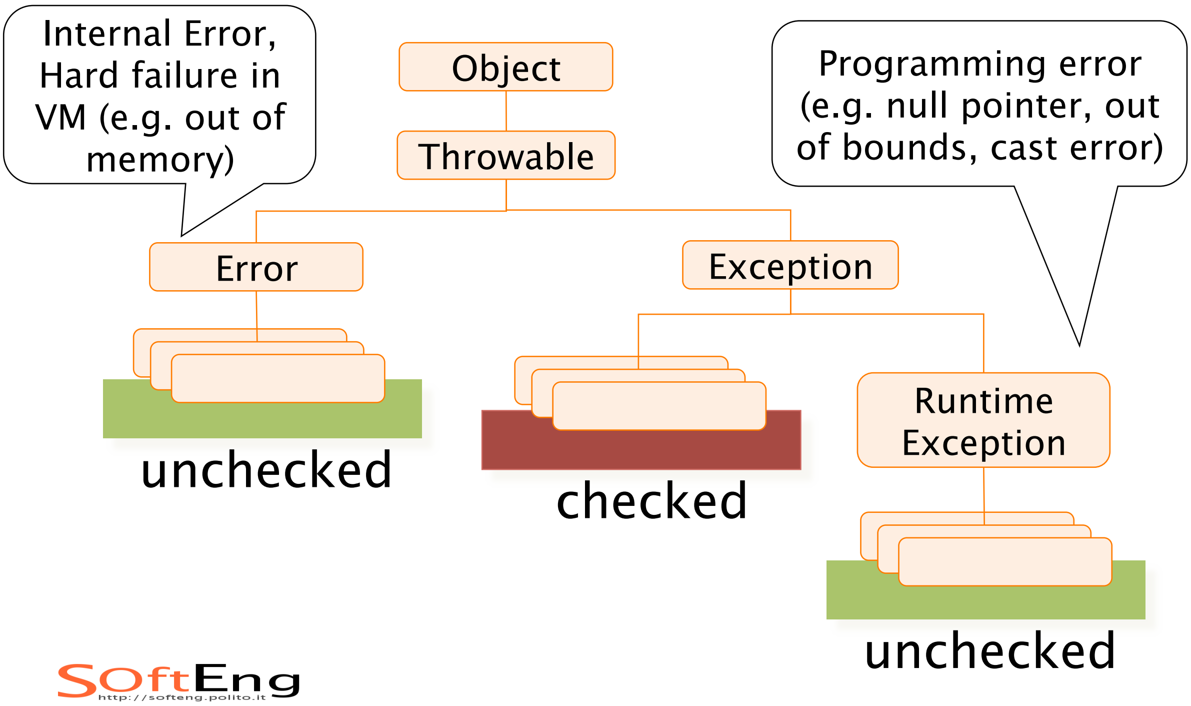
```
class Dummy {
   public void foo() throws FileNotFound {
      FileReader f = new FileReader("file.txt");
   }
}
```

```
class Program {
   public static
   void main(String args[]) throws FileNotFound {
      Dummy d = new Dummy();
      d.foo();
}
```

[3] Re-throw

```
class Dummy {
  public void foo() throws FileNotFound{
    try{
      FileReader f;
      f = new FileReader("file.txt");
    } catch (FileNotFound fnf) {
       // handle fnf, e.g., print it
       throw fnf;
    }
  }
}
```

Exceptions hierarchy


Internal Error, Hard failure in VM (e.g. out of memory)
Object
Throwable
Programming error (e.g. null pointer, out of bounds, cast error)
Error
Exception
unchecked
checked
Runtime Exception
unchecked

Exception classes – examples

- Error
  - OutOfMemoryError
- Exception
  - ClassNotFoundException
  - InstantiationException
  - NoSuchMethodException
  - IllegalAccessException
  - NegativeArraySizeException
  - EmptyStackException
- RuntimeException
  - NullPointerException

Custom exceptions

- It is possible to define new types of exceptions
- If the ones provided by the system are not enough…
- Just sub-classing Throwable or one of its descendants

Checked and unchecked

- Unchecked exceptions
  - ♦ Their generation is not foreseen (can happen everywhere)
  - ♦ Need not to be declared (not checked by the compiler)
  - ♦ Generated by JVM
- Checked exceptions
  - ♦ Exceptions declared and checked
  - ♦ Generated with “throw”

finally

- The keyword finally allows specifying actions that must be always executed
  - Dispose resources
  - Close a file

After all catch branches (if any)

```
MyFile f = new MyFile();
if (f.open(“myfile.txt")) {
   try {
      exceptionalMethod();
   } finally {
      f.close();
   }
}
```

Exceptions and loops (I)

- For errors affecting a single iteration, the try-catch blocks is nested in the loop.
- In case of exception the execution goes to the catch block and then proceed with the next iteration.

```
while(true){
   try{
     // potential exceptions
   }catch(AnException e){
     // handle the anomaly
   }
}
```

Exceptions and loops (II)

- For serious errors compromising the whole loop the loop is nested within the try block.
- In case of exception the execution goes to the catch block, thus exiting the loop.

```
try{
    while(true){
       // potential exceptions
    }
}catch(AnException e){
    // print error message
}
```

Testing exceptions

- Two main cases shall be checked:
- We expect an anomaly and therefore an exception should be rised
  - In this case the tests fails whether NO exception is detected
- We expect a normal behavior and therefore no exception should be raised
  - In this case the tests fails whether that exception in raised

Expected exception test

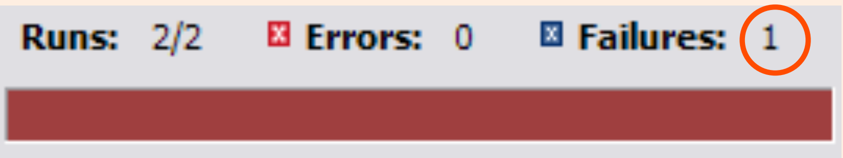
```
try{
  //  e.g. method invoked with “wrong” args
  obj.method(null);
  fail(“Methdo didn’t detected an anomaly");
}catch(PossibleException e){
  assertTrue(true); // OK
}
```

```
class TheClassUnderTest {
 public void method(String p)
       throws PossibleException
  { /*... */ }
}
```

Unexpected exception test

```
try{
  //  e.g. method invoked with right args
  obj.method(“Right Argument");
  assertTrue(true); // OK
}catch(PossibleException e){
 fail(“Method should not raise except.");
}
```

Exception → Failure

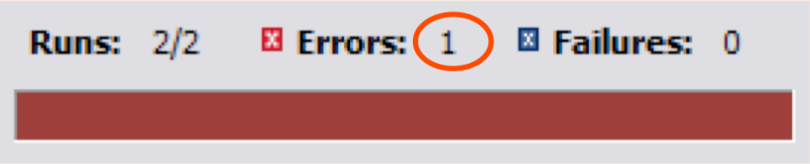


Runs: 2/2 ☒ Errors: 0 ☒ Failures: 1

Unexpected exception test

```
public void testSomething()
      throws PossibleException {
   // e.g. method invoked with right args
   obj.method(“Right Argument");
}
```

Eccezione ➔ Error



Runs: 2/2 ☒ Errors: 1 ☒ Failures: 0

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